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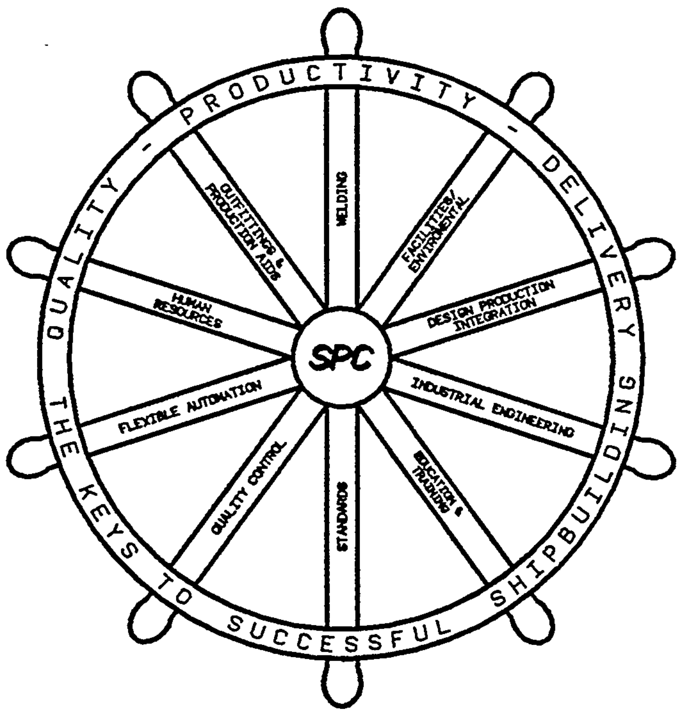

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On the Job Training in Line Heating in Astilleros Espanoles Shipyards, A Profitable Experience

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ABSTRACT

This paper describes the experience in teaching Astilleros Españoles(AESA)' steel fabrication workers in the practical use of line heating (L/H) for accurate bending of plates, and the operational deployment of this technology in all shipyards in the group. This project is set within the developing dimensional accuracy improvement program, which is aimed at improving productivity, quality and allowing the implementation of a continuous improvement process.

The approach used is for facilitating a systematic technology transfer from Japanese specialists, *overcoming* initial reluctance, promoting active participation with a commitment from workers and foremen, and assuring practical documentation of experiences in the form of a shop operating manual.

THE ACCURACY TARGET

In April 1990 a key document for the ongoing technological change was issued by the group's top management under the name of PIMET, which stands for "Plan Integral de Mejoras Tecnológicas" (Global Plan for Technological Improvement)(l). This document established the Japanese shipbuilding industry as a model of reference, and emphasized its main logic and principles.

The PIMET consistently recognized accuracy control (A/C) as one of the main elements for achieving world class productivity, and required each one of the group's shipyards to establish A/C related projects. One of these projects was the development of the operating capacity for forming plates by line heating, with the purpose of producing accurate parts for the downstream users.

L/H for fairing purposes was introduced in Spain around 1956 by a Finnish Company called TAMPO. Since then distortion removal was done by workers known as "TAMPO specialists", but in all that time L/H had rarely been used for bending purposes, and only as an auxiliary technique at the steel fabrication shops. Furthermore, due to the non-systematical process of knowledge transfer and the lack of written procedures, most of the profitable know-how was unfortunately lost for the time that the PIMET was issued.

THE FIRST APPROACH SHIPYARDS SELF-TRAINING AND IMPLEMENTATION

As pointed out by Messrs. R. Gutiérrez and A. Sarabia (2), the NSRP of the U.S. has been an extraordinary source of information to AESA, both for identifying development opportunities and designing ad-hoc policies, as well as for preparing internal documents on key technical topics. From that source succesful results obtained in some U.S. shipyards on L/H training were "discovered", and a publication (3) on the practical use of this technique, which in November 1990 was translated into Spanish, was released to all shipyards as a guide for self-training. However, after several months no progress had been made and only a few shipyards had made some erratic and unsuccessful trials.

LOOKING FOR A GUIDED IMPLEMENTATION THE TESTING PROGRAM AT SEVILLA SHIPYARD

To solve the difficulties which appeared to arise at the shipyards in implementing L/H practices, and to give them enough confidence to proceed by themselves, company's top management decided to launch a systematic program of practical L/H experiences based at one of the shipyards, concentrating all necessary internal and external support. The program would be managed by the Industrial Development Department at the company's head office. Sevilla shipyard, reputed as a pioneer in introducing many technological changes in Spanish shipbuilding history, was chosen for that purpose. In April 1991 a kick-off meeting was held with all responsible persons from the different shipyards.

The first phase of the program covered checking and measuring bending and shrinkage effects, identification of more efficient combustion parameters, torches, tips, travel speed and flame-plate and flame-water distances, the effects of jigs and of mechanical stressing by dogs and wedges, and the study of the metallurgical and mechanical conditions left by the heat inputs and stresses involved in L/H processing. All the

tests were made on plate samples of different thicknesses covering applicable ranges.

From the results of this phase the following was established.

1. The use of large flame (aprox 800 mm.) propane Harris torches,

2. The use of type M Koike tips models L-4000 for thickness lower than 10 mm, and L-5000 for higher thickness,

3. The use of a torch tip to plate distance (Table I) in between 20 and 28 mm depending upon the plate thickness,

4. The use of a water jet to flame distance of about 100 mm. when water cooling were to be applied on the same plate face than heating.

Working under these conditions the maximum temperature (measured by thermocouples at 2 mm. below the surface) does not exceed 650°C. Thus L/H forming does not induce any major deterioration on the plate material and the resultant toughness (Table II) is not lower than that associated with forming, for example, by roller.

MATERIAL	GROUP	THICKNESS (mm.)	OPTIMUM TIP-PLATE DISTANCE (mm.)
ORDINARY-STRENGTH STEEL. GRADE A	1 2 3 4	12:14 15:18 19:24 25:40	20 20 20 28
HIGHER-STRENGTH STEEL. GRADE AH	1 2 3	14:15 16:18 19:20	20 20 20

Table I: Optimum tip-plate distance

FORMING BY	MICRO-STRUCTURE	TEMPERATURE °C	CHARPY IMPACT TEST (J) (notch on plate surface)		
			1	2	3
ROLLER	FERRITE-PEARLITE	ROOM	122	297	282
L/H	FERRITE-PEARLITE	720°C	246	278	298

Table II: Ordinary-strength steel, grade A, thickness 14 mm.

Other practical results obtained *were:*

1. Combustion parameters and torch travel speeds to use to limit a maximum temperature to 650°C without loosing bending efficiency (Tables III and IV),

2. What levels of bending and shrinkage could be expected (Tables V and VI) for many of the possible combinations plate thickness/-plate quality/torch travel speed,

3. The effects of succesive superimposed heat lines,

4. How to use wedges and dogs efficiently to control and correct curvature.

GROUP #	THICK NESS (mm.)	PRESSURE (kg/cm^2)		FLOW (L/H)		OPTIMUM TORCH TIP-PLATE SEPARATION (mm)	MINIMUM TORCH-SPEED (mm./min.)
		PROPANE	OXYGEN	PROPANE	OXYGEN		
1	12:14	0.8	5.8	1.500	7.000	20	400
2	15:18	0.8	5.8	2.200	10.000	20	300
3	19:24	0.8	5.8	2.600	13.000	20	300
4	25:40	0.8	5.8	3.200	16.000	28	250

Table III: Ordinary-strength steel, grade A.

GROUP #	THICK NESS (mm.)	PRESSURE (kg/cm^2)		FLOW (L/H)		OPTIMUM TORCH TIP-PLATE SEPARATION (mm)	MINIMUM TORCH-SPEED (mm./min.)
		PROPANE	OXYGEN	PROPANE	OXYGEN		
1	14:15	0.8	5.8	1.500	7.000	20	300
2	16:18	0.8	5.8	2.200	10.500	20	300
3	19:20	0.8	5.8	2.800	13.500	20	300

Table IV: Higher-strength, grade AH.

Finally, people involved in this first phase were able to design basic line heating procedures for some simple forms, including number of lines and torch travel speeds to be applied, and to perform them successfully.

The second phase of the testing program (which took place in two different shipyards) was mainly devoted to screen triangular heating/cooling cycles and the fracture toughness of the materials. When L/H forming schemes include triangle heating, Tables VII and VIII show that heating up to a temperature of 900°C and water cooling once the temperature is at or below 500°C does not reduce toughness below the minimum required by standards. However, from the point of view of that material characteristic, it would be much better to work with temperatures not exceeding 850°C.

Both experimental phases were thoroughly documented, and the different documents were sent to all shipyards to be released to their steel fabrication shops. Pertinent people were directed to study them, fabricate some simple forms following basic L/H principles and operations, there contained and record any difficulties they encountered.

After this the different shipyards appeared to be confident with the technique, and prepared to "learn the practice".

GROUP #	THICK NESS (mm.)	TORCH SPEED (mm/min.)	TEMPER ATURE °C	ANGULAR DISTORTION (degrees)
1	12 14	400 300	500 550	1,3 1,2
2	15 16 18	300 300 300	500 500 500	1,0 1,0 1,0
3	19 20 22	300 250 200	500 600 600	1,2 1,1 1,0
4	25 28 30 40	200 250 250 250	600 500 500 500	1,3 1,0 0,9 0,6

Table V: Ordinary-strength steel, grade A.

GROUP #	THICK NESS (mm.)	TORCH SPEED (mm/min.)	TEMPER ATURE °C	ANGULAR DISTORTION (degrees)
1	14 15	300 300	500 500	1,1 1,0
2	16 17 18	300 300 300	500 500 500	1,2 1,2 1,1
3	19 20	300 300	500 500	1,2 1,0

Table VI: Higher-strength, grade AH.

SPECIMEN	ZONE	TEST TEMPER ATURE	ABSORBED ENERGY (J)	IMPACT STRENGTH (mm)	DUCTILE FRACTURE
A-1 (14 mm.)	HEATED	0°C	72	1.06	50%
	NON HEATED	0°C	111	1.43	60%
A-2 (28 mm.)	HEATED	0°C	46	0.78	55%
	NON HEATED	0°C	88	1.36	85%

Table VII: Fracture toughness test results. Ordinary-strength steel, grade A. Minimum required value according to ABS 27.4 J. for plate thickness ≥2" at 20°C.

SPECIMEN	CHARPY V-NOTCH ASTM A-370	NOTCH ON SURFACE
	ABSORBED ENERGY (J)	ABSORBED ENERGY (J)
Before Forming	105	180
After Rolling Long Radius Side	102	172
After Rolling Short Radius Side	97	183
Triangle at 900°C Water cooling < 400°C	109	162
Triangle at 900°C Water cooling < 500°C	62.5	158
Triangle at 900°C Water cooling < 600°C	21	98
Triangle at 850°C Water cooling < 500°C	98	
Triangle at 800°C Water cooling < 500°C	88	
Triangle at 750°C Water cooling < 500°C	96	
Triangle at 700°C Water cooling < 500°C	94	

Table VIII: Fracture toughness tests results. Higher-strength steel, grade AH-36. Minimum required value according to ABS 34 J. at 0°C.

THE JAPANESE ARRIVAL TO SESTAO SHIPYARD

Knowing from the Journal of Ship Production and some NSRP technical publications of the important role played by Ishikawajima-Harima Heavy Industries in shipbuilding technology transfer to the U.S. during early the eighties, it was considered beneficial for the company to incorporate Japanese consultants to support the development of the PIMET. Following recommendations of Mr. L.D. Chirillo, Maritech Engineering Japan Company (MEJ) was contacted.

In May 1991 was asked to visit Sestao shipyard in order to evaluate its production system. It soon became clear that the company could benefit from these consulting services. In October an agreement was signed for a two-year term to support a shipyard productivity improvement project; L/H Skill development was one of the issues where support was immediately required.

The first L/H demonstration sessions by the Japanese experts took place at the end of June in Sevilla shipyard, where a company testing program was being developed with the help of Spanish consultants.

THE TRAINING PROGRAM GOALS AND PRINCIPLES

Goals

From the very beginning the training program was targeted to fulfill three main goals:

1. Deploy the L/H technique throughout all of the group’s steel fabrication shops in a short period of time,
2. Promote awareness among workers and foremen of the critical importance of accuracy, and
3. Develop a practical shop L/H Operating Manual in order to assure the control of the know-how in the company and so to guarantee the quality of the training of new workers.

The training had to cover workers and foremen from many shipyards. In total about thirty five people

were chosen, who would later spread their knowledge among other teams in the shipyards.

The objective was to train skilled workers, very much attached to the use of rollers and presses, and traditionally more concerned with productivity than accuracy. Because of this, the emphasis at this stage had to be accuracy.

Documenting all the training experience in detail in a practical way was considered necessary to the project, in order to avoid losing the new technique. The importance of assuring to owners and classification societies that quality requirements are met through appropriate controls in the shops on plate heating and cooling conditions was covered by the training system documents. Therefore, appropriate tests were established to determine practical operating and control conditions.

Principles

The L/H training program was established according to the following principles.

1. It would be basically organized as on-the-job training sessions at the lead shipyard under the control of the L/H Japanese expert, with practice periods at each of the other individual shipyard.

2. Classroom sessions would be held at the end of each training period at the lead shipyard, and at any other time deemed necessary. All workers' questions would be systematically gathered before each session and addressed to the expert.

3. The training program would take place during a fifteen-month period, with five two-week long sessions led by the Japanese expert.

4. The program should progressively cover plates of all grades of difficulty.

5. The group's head office would coordinate the program through its development department, including the continuous evaluation of the progress, and implementation of necessary feed-back actions.

DOCUMENTATION, THE L/H OPERATING MANUAL

In order to assure the systematic documentation of L/H technology, and the preparation of the L/H operating manual (4), a Spanish consultancy firm already working in the L/H practical experiences program at another shipyard was assigned to perform the documentation task.

Operating procedures followed by the expert were fully documented and distributed to every shipyard. Representative examples of plates of different degrees of difficulty were used. Procedures included a step-by-step description of each plate bending history, accompanied by photographs and detail figures. The same procedure was followed for documenting the more representative classroom questions and answers.

As a result of this documentation effort, an L/H operating manual was prepared, aimed to facilitate the training of the foremen and workers at the steel fabrication shops. The manual was distributed to the shops, and meetings were held at each shipyard to review the main concepts; these meetings also guaranteed that the workers read the document. A draft of the manual already had been sent to the shipyards for comments.

The manual covers, in a simple shop language all the necessary information: from very general concepts and techniques, to very detailed practical solutions to particular cases. The main sections of the manual are:

- Basic Principles,
- Required Facilities,
- Heating and Cooling Conditions,
- Temperature Control,
- Sight Line Templates,
- Heat Application Techniques, and
- Forming Criteria and Schemes.

The Manual will be kept current through a periodic review process that will guarantee the incorporation of the accumulated experience of all the shops.

WORKER'S ATTITUDE

The L/H project was viewed favorably by shipyard representatives at the kick-off meeting held in April 1991. However this good disposition was accompanied by a certain concern about the capacity of the company to develop and implement the L/H technology without external support.

The support of outside experts and specifically, their knowledge, experience, authority and commitment has been the key for the quick deployment of L/H in the various shops. However it must be pointed out that just following systematically the NSRP L/H technical document would allow any shop to begin practicing the technique.

The attitude of the workers and foremen for learning this new technique has been in general very positive. Since the first demonstration in June 1991, they have participated very actively in the training sessions and implemented the technique in real production in their shops, with the strong support of the

shop managers. The L/H operating manual has benefited greatly from their acute observations and feedback on practical operating details.

FUTURE WORK

Short term

Although the L/H technique is in general operative in all of the group's shipyards, the level of expertise and/or fulfillment of capacity needs are not yet totally satisfactory in some shipyards. Because of this, new on-the-job training courses are being developed to solve the problems.

From now on, the shops will have to concentrate on improving efficiency through a better combined use of L/H and of cold forming with available mechanical means. Also, they will need to follow the L/H operating manual recomendations and their own accumulated experience.

Accuracy, which is being statistically tracked, will be further improved through better template construction, and implementation of new procedures to diminish errors in the setting of angles with plates.

The public yards are also helping all privately owned Spanish shipyards to introduce L/H in their bending shops.

Long term

As part of the FASP (Flexible Automation in Ship Prefabrication)[1], research has begun on the design and construction of a line heating system for semi-automatically forming hull plates to a predetermined shape. The system development is planned for operation by a worker highly skilled in manually applied L/H. The CNC system is thought to be programmed on-line.

The system will be provided with manual plate clamping and stressing means, and a vision system for automatically measuring plate deformation at each bending process step. The system will be linked to a CAD system through the appropriate interface.

CONCLUSION

The results of this fifteen-month training program have been very satisfactory. Technology transfer was finished last September, and the skill level of our workers, especially in the case of Sestao shipyard, has been rated by the Japanese consultants as equivalent to a Japanese worker with five years of experience.

Assembly section workers recognized major improvements in plate accuracy: this has not only increased assembly productivity, but has also contributed to a more self-demanding attitude of the assembly workers with respect to their own work accuracy. Improvements in quality of assembly plattens, and demands for a better assembly-finished-curved-shell-marking procedure, are examples of this new attitude.

Another PIMET project that has benefited from the success of the L/H project is the Fairing Heat project. This project has followed the same kind of approach, and has received the invaluable support of Japanese experts.

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1 *The FASP project is part of the European Eureka program aimed to keep European shipyards competitive.*

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